User Centred Networked Health Care
A. Moen et al. (Eds.)
IOS Press, 2011
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doi:10.3233/978-1-60750-806-9-694

Ontology-based Framework for Electronic Health Records Interoperability

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Abstract. The use of Electronic Health Records (EHR) is wide spread in healthcare. One of the most challenging tasks for EHR systems is to achieve computable semantic interoperability. To address EHR interoperability, a number of standardization efforts are progressing, however these standards are either incomplete in terms of functionality or lacking specification of precise meaning of underlying data. This paper describes an interoperable EHR framework that uses an ontology-based approach to facilitate exchange of information and knowledge among EHR. Based on the proposed framework, an interoperability scenario between a Personal Health Record System, an EHR and a Laboratory System is described.

Keywords: Electronic Health Records, interoperability, HL7, ontologies.

1. Introduction

For meeting the challenge of improving quality and efficiency of patient's care, including homecare and prevention, electronic health records (EHR) have to support semantic interoperability [1]. EHR is simply defined as a repository of information regarding the health status of a subject of care [1]. It commonly combines information from a number of distributed health actors intervening in the same or chained care process, exchanging information, but normally not really collaborating. Health information is characterized as being data intensive, complex, changing, life-long, sensible, and policy regulated. In this sense, actors - being human or computers - need to be intelligent enough to be able to process and share this information. Therefore, the most challenging task for EHR systems is to achieve computable semantic interoperability [3]. The goal of semantic interoperability is to be able to recognize and process semantically equivalent information homogeneously, even if instances are heterogeneously represented, i.e., if they are differently structured, and/or using different terminology systems, and/or using different natural languages. This equivalence needs to be robustly computable, and not just human readable, in order for guidelines, care pathways, alerting and decision support components to function effectively and safely across EHR that have been combined from heterogeneous systems [4]. The objective of this paper is to propose an interoperability framework that uses an ontology-based approach to support semantic interoperability among Electronic Health Records regardless of the EHR standard used.

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2. Methods

For guaranteeing computable semantic interoperability between components of a complex system, the system's architecture is important, i.e., the composition of the right components regarding their structure, behavior and relationships. The Generic Component Model (GCM) [5] provides an architectural framework created with the purpose of analyzing any kind of system, including EHR. Specially, GCM addresses the real world challenge of multidisciplinary domains involved in any EHR through ontology harmonization (mapping). From the philosophical perspective, ontology is a representation of the universals or classes of reality and the relations existing between them. Hereby, universals are "the real invariants or patterns in the world apprehended by the specific sciences" [6]. From a more restricted perspective, a commonly accepted definition for ontologies in computer science is the one provided by Gruber [7] defining ontology as ‘‘a specification of a conceptualization", i.e. the provision of knowledge representation primitives (classes, attributes and relationships) to model reality. The latter definition differs from the philosophical perspective which categorizes things of reality without interpreting, i.e. conceptualizing them. The above described divergence could be clarified using the GCM to provide a system of ontologies, with the universal (philosophical) ontology on top explaining the nature of the world, followed by reference ontologies (top-level) bridging between the "network" of domain ontologies, from which the latter as well as the application ontologies (i.e. implementation of the knowledge of business transactions) in the bottom are derived.

In distributed environments, provide a single ontology describing the Universe is not possible. Several ontologies are independently designed according to the knowledge domain represented. In order to achieve semantic interoperability among ontology-based applications, it is necessary to harmonize their ontologies. There are two ways for ontology harmonization (mapping): the first is the development/extension of domain ontologies from a common top level ontology; the second is the harmonization of characteristics of those domain ontologies such as their structure, definitions of concepts, instances of classes, to find mappings. The approach presented in this paper follows the ontology harmonization approach from a common top level ontology.

3. Results

3.1. Interoperability Framework for EHR Semantic Interoperability

The proposed framework aims at supporting the requirements for semantic interoperability in EHR. Figure 1 illustrates the proposed approach.

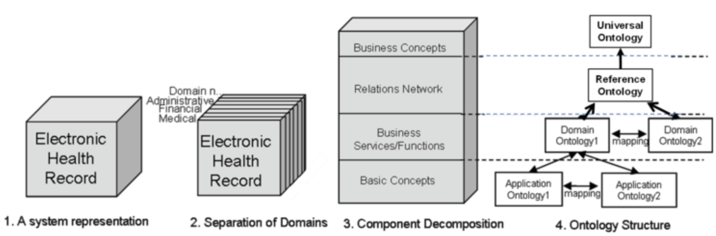

Figure 1. GCM Architectural Dimension

The architectural framework is based on the GCM [5]. In the first stage, the GCM allows to describe the real system to be analyzed (i.e. EHR). In the second stage, the GCM domain dimension is used to separate different domains for reducing complexity of inter-related domains (e.g. medical, financial, administrative, etc). The third step allows reducing structural and behavioural complexity of the EHR by decomposing it. The four granularity levels defined in GCM are considered and analyzed (details (e.g. basic concepts), aggregations (e.g. business services), relations networks and business concepts). This step aims at defining domain knowledge to achieve semantic interoperability. In this sense, the domain description is based on domain ontologies, and each granularity level is associated with its corresponding ontology. In the fourth step, the ontology structure is described. According to the granularity level of the EHR system, the aforementioned ontology architecture is used. The different ontologies can be inter-related which requires ontology mapping. In our approach, a detailed concept within an EHR – the GCM Details level – is provided by a domain-specific application and represented using an application ontology derived from that domain's ontology (domain ontology). At the level of aggregated services (GCM Aggregations level) usually provided by different applications in a domain, the application ontologies have to be mapped at that domain ontology. For representing multi-domain concepts provided by applications from different domains, the GCM Relations Network level applies. To combine representation of different domains the domain ontologies have to be mapped through reference ontologies. To guarantee that the multidisciplinary approach fits the reality, the system of ontologies applied has to be proven at the universal ontology. In other words, the reference ontologies must be derived from universal ontology. As the EHR is a multidisciplinary system, the entire system of ontologies has to be deployed for its representation. In the next section the ontology mapping process is described.

3.2. The Ontology Mapping Process

The mapping between ontologies is apparently a smooth process. However, finding adequate mappings is not easy due to the semantic heterogeneity problem of EHR (lack of common vocabularies). In this sense, an effective method to solve the ontology heterogeneity problem by finding and solving mismatches without human intervention is proposed. Figure 2 presents the proposed mapping process phases [8] as described below:

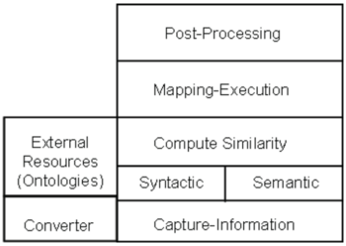

Figure 2. Mapping Process Phases (adapted from [8])

a) Capture Information: In this phase, formal application ontologies are created for each EHR to interoperate. For this process, the application domain concepts found are represented using the Web Ontology Language (OWL), thereby obtaining the formal application ontology for each application. Application domain concepts are commonly represented as data-models using different representation languages or formats (Entity-Relationship models, object-oriented models, UML or XML specifications, etc). A converter component is used to transform the different information models into formal application ontologies encoded in OWL, using different mechanisms.

b) Compute Similarity Ontology: In this phase, individual matching mechanisms are used. The matcher takes as input the two formal application ontologies and returns a

similarity matrix. The mapping execution process is shown in Figure 3. Following, the selected matcher mechanism are described:
Entity-based: Normalization is provided for reducing strings (concepts, entities) to be compared. The normalization process includes: (i) case normalization, (ii) diacritics suppression, (iii) blank normalisation, (iv) link stripping, (v) digit suppression, and (vi) punctuation elimination.
Semantic-based: Domain and/or reference ontologies are used. The approach takes into account that the two ontologies to be matched lack a common ground on which the comparison is performed. Therefore, intermediate ontologies (domain or reference ontologies depending of the granularity level) are used. Those ontologies define the common context or background knowledge, supporting disambiguation of multiple possible meanings of concepts and relationships.
c) Mapping Post-Processing: In this phase, correctness and consistency of the generated mappings is checked (i.e. recall and precision). In this work, a deductive approach is used, based on description logics (DL).

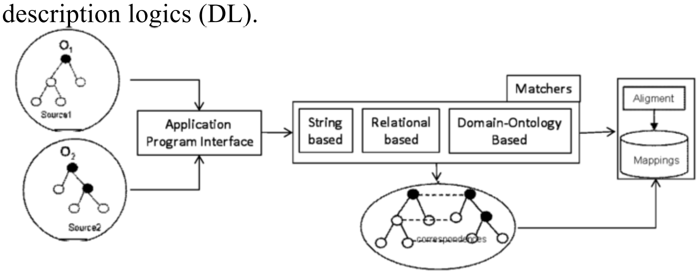

Figure 3. Mapping Execution

3.3. An Interoperability Scenario in Health

In Figure 4, an interoperability scenario between the Personally Controlled Health Record System (PCHR) Indivo, OpenMRS EHR, and a Laboratory System BikaLIMS is shown. Below the system actors and interactions are briefly described:
Patient: The patient uses the PCHR-Indivo to manage personal clinical information. She performs three use cases: account provisioning, record access, and populating the record with data.
Medical Doctor: The medical doctor uses the OpenMRS system to store diagnosis, tests, procedures, drugs, and other patient related information. Furthermore, it communicates with other systems (i.e. laboratory system).
Interactions: The scenario starts when the patient requests an examination. Once the medical doctor has logged into the system, he looks for patient information and modifies the medical record, registering a diagnosis, treatment, etc. In the scenario, the medical doctor orders a laboratory test, which is sent to the LIMS laboratory system. LIMS processes the order and returns the results to OpenMRS, which updates the patient registry. Once the information has been updated, the doctor sends a message to the PCHR-Indivo system.

The proposed interoperability framework supports the aforementioned interaction process. The first step corresponds to the conceptual models' formalization. The conceptual models of the three systems intended to interoperate are translated into formal application ontologies using OWL. Next, the mapping between those ontologies is executed. In this process, the mechanisms described in section 3.2 are used, and a set of top level and domain ontologies is required to guarantee the mapping process quality. Finally, the generated mapping is checked in order to verify its consistence.

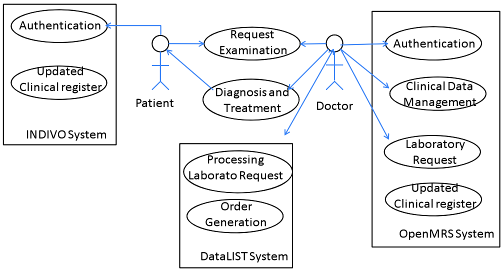

Figure 4. Interoperability Scenario

4. Discussion and Conclusion

EHR interoperability standards and revised related work on approaches for semantic interoperability [3], are either incomplete in terms of functionality or lack the specification of the precise meaning of the underlying data. In this paper the use of a framework for ontology-based semantic interoperability has been described. This approach is presented as a service for integrating different EHR systems. The semantic interoperability scenario has been demonstrated for a real business case meeting user requirements. The prototype includes three systems: INDIVO, OpenMRS and BikaLIMS. In the implementation process, the use of formal application ontologies was necessary, thus improving the information representation of each system to interoperate. Also domain ontologies were used in order to guarantee the correctness of the information to be exchanged. The prototype is currently tested in order to determine the effectiveness of the matching process and the accuracy of the exchanged information.

Acknowledgments. The work was supported by NIH Fogarty (D43TW008438) and University of Cauca.

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